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CRYOGENIC COOLING SYSTEM FOR THE GROUND TEST ACCELERATOR

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ABSTRACT

A cryogenic cooling system has been designed, built and tested for the Ground Test Accelerator (GTA) at the Los Alamos National Laboratory. Major components of the GTA require cooling to less than 50 K to reduce rf-heating and to increase thermal stability. The cooling system is capable of cooling (at an acceptable rate for thermal stresses) the cryogenically cooled components and then maintaining them at their operating temperature during accelerator testing for all modes and power levels of operation. The accelerator components are cooled by circulating cold, dense helium gas (about 21 K and 2.1 MPa) through the components. The circulating helium is refrigerated in a heat exchanger that uses boiling liquid hydrogen as a source of refrigeration. The cryogenic cooling system consists of the following major components: a liquid hydrogen (LH_2) storage Dewar with a transfer line to an LH_2 run tank containing an LH_2/gaseous helium (GHe) heat exchanger, circulation lines, and a circulation pump. The system, sized to cool a load of approximately 40 kW at temperatures as low as 20 K, is operational, but has not yet been operated in conjunction with the accelerator.

INTRODUCTION

The GTA at the Los Alamos National Laboratory is an integrated-system test facility for evaluation of the use of neutral particle beams as a part of the Strategic Defense Initiative. The project is managed by the U.S. Army Strategic Defense Command for the Strategic Defense Initiative Office.

The conceptual design and detailed specifications for the Cryogenic Cooling System (CCS) were developed by the Laboratory. As a result of competitive bidding, a contract for design, procurement, fabrication, installation and acceptance testing of the CCS was awarded to CVI, Inc.

The operation of the GTA at cryogenic temperature has two advantages[1,2]. First, the lower temperature produces a corresponding decrease in the rf-heating of the copper in the various components of the accelerator, and second, the decrease in the thermal expansion coefficient with decreasing temperature provides greater thermal stability and consequently, better operating stability for the accelerator. Although the ratio of the electrical resistance of copper at room temperature to that at cryogenic temperature (RRR) can attain values well above 100, this comparison does not hold for rf-heating. A typical theoretical ratio for rf-heating power for copper is shown in Fig. 1, which shows that most of the advantage of cryogenic cooling is obtained when the temperature is lowered to 50 K. A similar examination of the decrease of the thermal expansion coefficient shows that most of the advantage in thermal stability is also obtained when the temperature is lowered to the vicinity of 50 K, where the reduction is sufficient to permit satisfactory operation of the accelerator, provided the temperature variation during operation can be limited to 1 or 2 K.

Thus, GTA operation requires that the cryogenic cooling system: (1) cool part, or all, of the entire system to operating temperature (less than 50 K), without excessive thermal shock to any of its components; (2) maintain the operating temperature for extended periods; and, (3) warm the components to ambient temperature at a controlled rate. The only fluids that can accommodate the requirement of operation below 50 K are neon, hydrogen, and helium.

The least expensive method of providing the refrigeration required for the intermittent cooling during the test program is the use of liquid hydrogen that can be delivered to, and stored at, the test site. The normal boiling temperature of LH_2 (20 K) is close to the lowest temperature that is conveniently available for space applications. This temperature is also sufficiently low to permit operation of the accelerator below 50 K while allowing for the temperature rise of the coolant that is necessary for single phase cooling, and allowing for the unavoidable temperature gradients within the accelerator components. However, because of safety restrictions, it is desirable to avoid the introduction of the hydrogen into the structure housing the accelerator. For this reason the use of an intermediate coolant (a so-called referee fluid) was selected, with the only two possible fluids being neon or helium. The considerations involved in the selection of cold, dense helium gas instead of liquid neon have been discussed in detail elsewhere[2].

These considerations included the expense of the neon gas; for neon, the necessity of operation at a higher pressure to preclude any operation in the two-phase regime; for helium, the greater ease of pressure control with changes in system cooling load; and the more complete knowledge of the properties of helium compared to those of neon, especially with respect to properties related to heat transfer.

SYSTEM DESCRIPTION

A schematic of the selected cooling system for the GTA is shown in Fig. 2. This system allows the GTA to be cooled at as slow a rate as necessary to avoid excess thermal gradients (consequently, also avoiding excess thermal stresses).

The cryogenic cooling system obtains its refrigeration capability from LH_2 purchased from a supplier and delivered to the GTA facility in a 50,000 liter (13,000 gallon) transport trailer. The liquid hydrogen is stored in a 106,000 liter (28,000 gallon) storage Dewar (see Fig. 3) and transferred through a 3.8 cm (1-1/2 in.) vacuum-jacketed transfer line to the run Dewar (see Fig. 4). The hydrogen run Dewar contains a helium-to-hydrogen heat exchanger to conduct the helium gas referee fluid through the pool-boiling hydrogen. Additional refrigeration is obtained by using the 20 K boil-off hydrogen vapor to cool the returning helium gas (at 35 K) in an auxiliary heat exchanger before the hydrogen is exhausted and burned in a flare stack.

The heat exchanger is connected to vacuum jacketed cryogenic transfer lines, which lead to a circulation compressor and to the GTA. The helium circulation system primarily consists of 7.6 cm (3 in.) vacuum-jacketed "go" and "return" lines. The primary cooling system also contains a liquid-nitrogen (LN_2) run Dewar (see Fig. 4) with liquid-nitrogen to helium heat exchanger to allow the use of low cost LN_2 for preliminary cool-down and standby operation of the system at 77 K. A 40 kW heater is used for rapid, but controlled, warmup of the GTA. The valving and piping system permits passage of the helium referee fluid through either: (1) the LH_2 run Dewar; (2) the LN_2 run Dewar; (3) a purifier; or (4) the warmup heater; and partially, or completely bypass all of these items. Most of this equipment is shown in Fig. 5. Thus, the cryogenic system can perform all of its necessary functions, and the heat generated in the operation of the GTA can be absorbed by the LH_2 evaporating in the run Dewar.

The accelerator heat load and pressure drop may be simulated by the warmup heater and control valve CV 151 (see Fig. 2).

Initially, the system, including the GHe-storage tank, is purged and then filled with pure GHe. Thereafter, the GTA and referee fluid system are charged with pure helium to the operating pressure of 2.1 MPa from this inventory of GHe. The helium gas is then circulated at ambient temperature through a purifier for one hour to remove trace amounts of moisture and other impurities. During cool down of the system GHe is added as needed to maintain the pressure at 2.1 MPa.

Cool-down begins with circulating the referee fluid through the heat exchanger in the LN_2 run Dewar. A program in the Allen Bradley computer control system controls the bypass of a fraction of the flow from the LN_2/GHe heat exchanger so as not to exceed a temperature differential of 50 K across the GTA. As the temperature of the GTA decreases, the bypass fraction is reduced by the controller until the bypass valve is fully closed and the bypass fraction becomes zero. When the temperature of the GTA approaches 80 K the flow of the referee fluid is redirected through the LH_2 run Dewar and the cooling process continues to the operating temperature of 20 K.

During a short standby period, cooling can be maintained with the referee fluid flowing through the LH_2 cooled heat exchanger. For longer standby periods the flow can be redirected through the LN_2 Dewar when the GTA has warmed to 75 K, and be maintained at that temperature as long as desired. Note that in all cases, the only fluid entering the GTA is the referee fluid. The system can remain on LH_2 standby for 36 h for no more expenditure of LH_2 than that required to cool the GTA from 77 to 20 K.

During the accelerator's transition from zero power to full power the temperature of the fluid in the return portion of the helium circulation system increases from 21 K to 35 K in a period of about one minute; consequently, some GHe is removed from the system with a two stage compressor to maintain a relatively constant operating pressure. The same two-stage compressor adds helium to maintain system pressure during reductions in GTA operating power (and consequent lowering of temperature in the return portion of the helium circulation system).

The cooling system is operational and has been tested at its maximum capacity of 40 kW at 20 K. This checkout operation was performed independently from the GTA by the use of the accelerator load valve CV151 in the GTA tunnel and the supply of heat from the 40 kW heater (see Fig. 2). CV151 also served to simulate the pressure drop through the GTA. A view of the CV151 and the piping in the tunnel is shown in Fig. 6

TESTING AND CHECKOUT RESULTS

The cryogenic cooling system has been checked out and successfully operated at its design point of 40 kW with the use of a dummy load. Figures 7 and 8 present the temperature and pressure histories of the checkout run. From Fig. 7, it can be seen that the cryogenic cooling system can be cooled from ambient temperature to 77 K in less than 180 minutes. The further cooling to 20 K takes about 60 minutes. The rise in return helium temperature to about 35 K during the application of 40 kW is evident in the time period from 400 to 470 minutes. The system was warmed back to ambient temperature in approximately 150 minutes. Because this was only a test of the cooling system, it must be noted that the cool down and warm up of the GTA will be slower, being dictated by the GTA mass to be cooled (or warmed) and the cooling rate and heating rate that it can tolerate.

Figure 8 shows the variation of pressure during the checkout run. The time period between 250 and 300 minutes shows drops in He pressure when the cool down is complete and when the cooling load is terminated. However, Fig. 8 shows that over the entire test period the pressure was maintained within a tolerable range.

CONCLUSION

The checkout run of the GTA cryogenic cooling system has shown that all systems are functioning satisfactorily. Cold, dense helium gas can be used as a referee fluid. Pressure control can be maintained through heat load changes, and the circulation compressor is capable of supplying the required He coolant flow at the required pressure drop.

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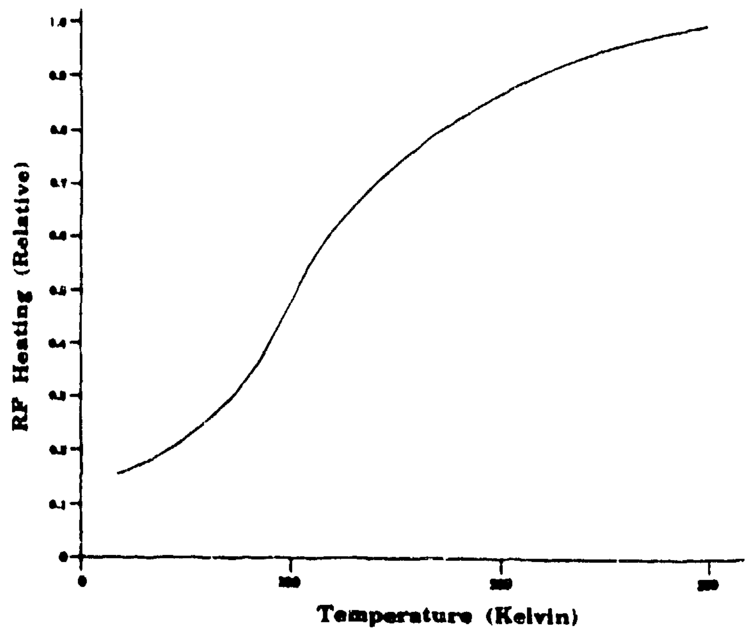


Fig. 1 Typical relationship of relative rf-heating of copper as a function of temperature showing a dramatic reduction in rf heating is obtained at low temperature. (This relationship is a function of RRR, surface treatment, and frequency.)

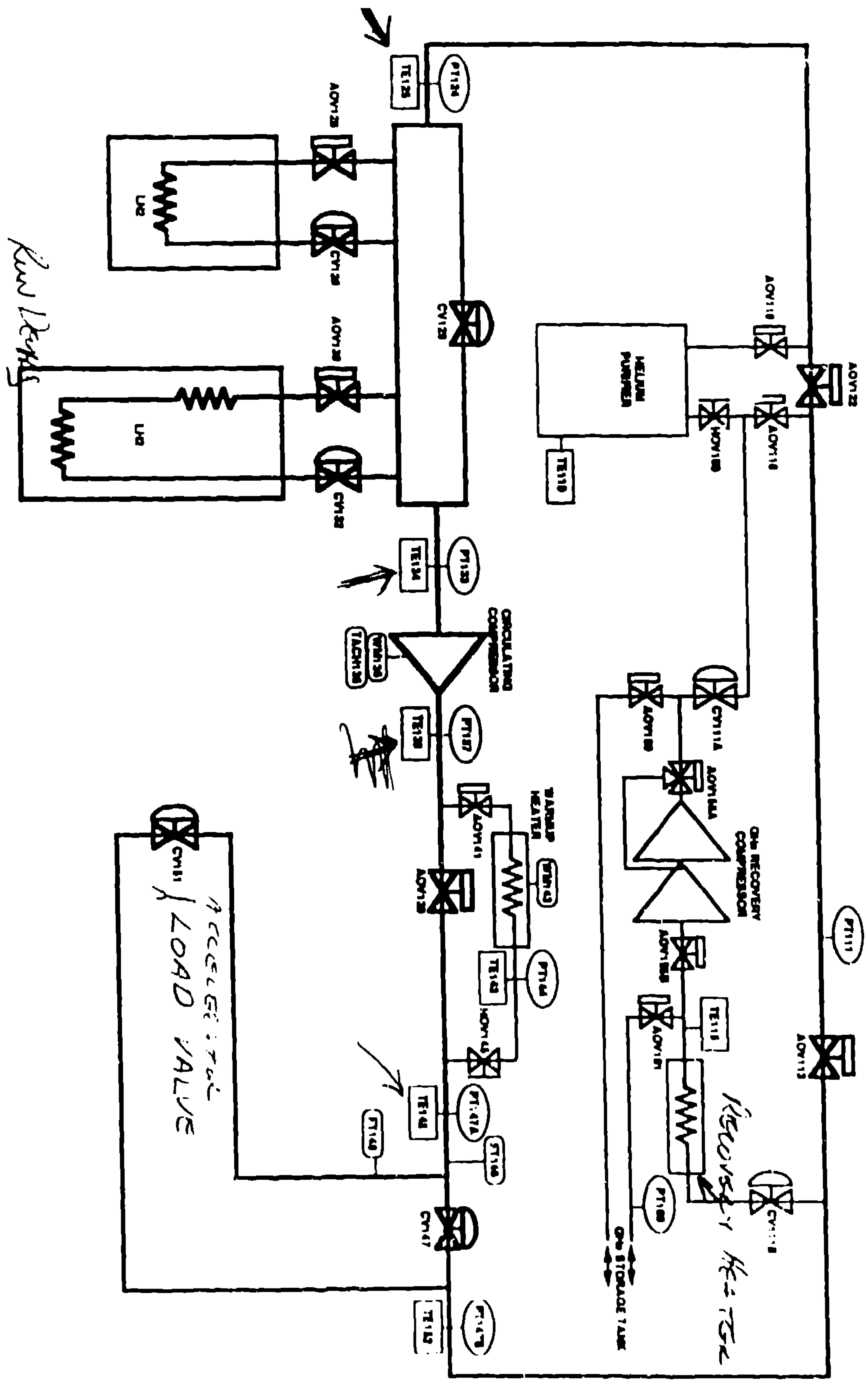
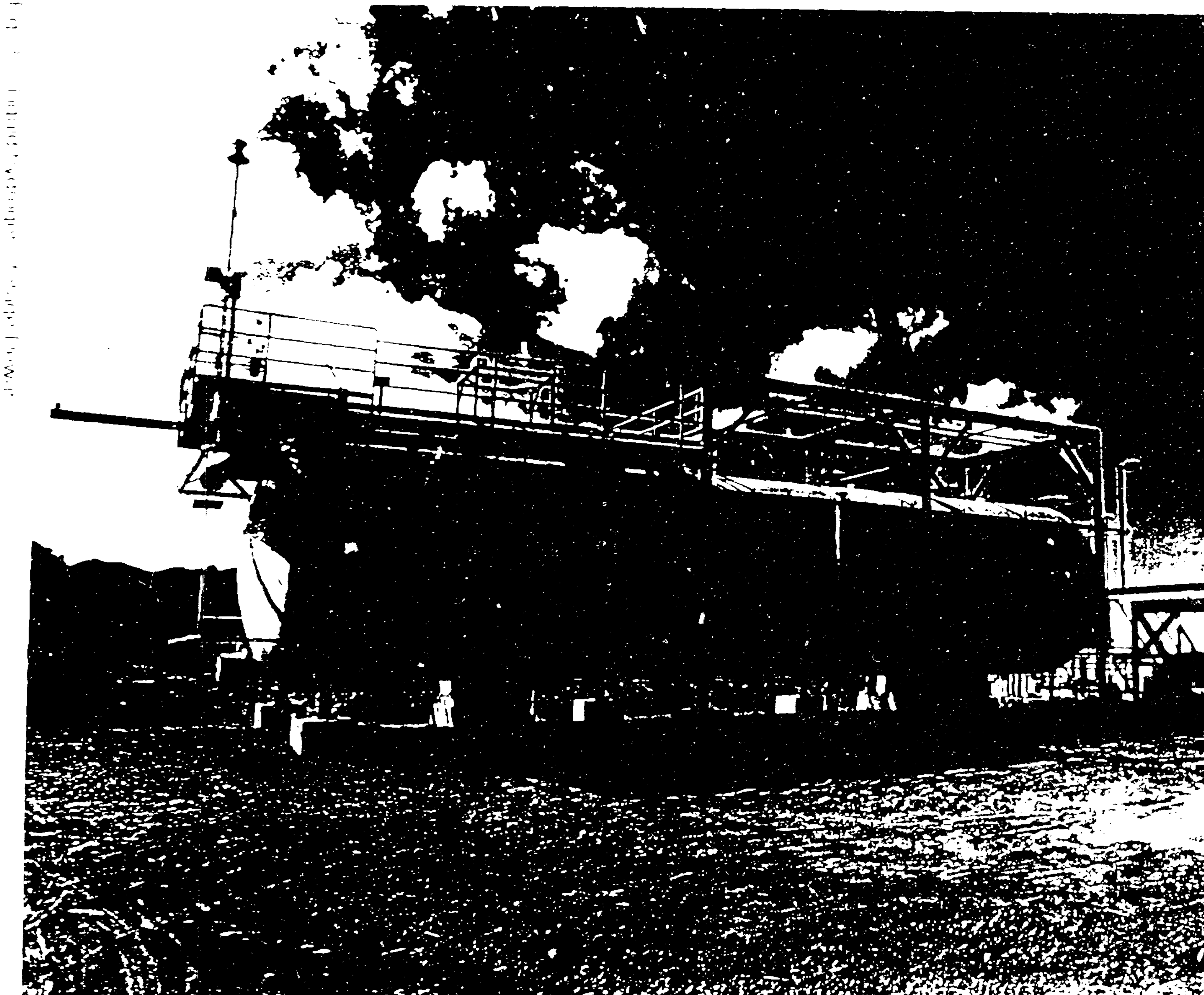


Fig. 2 Schematic of GTA Cyrogenic Cooling System



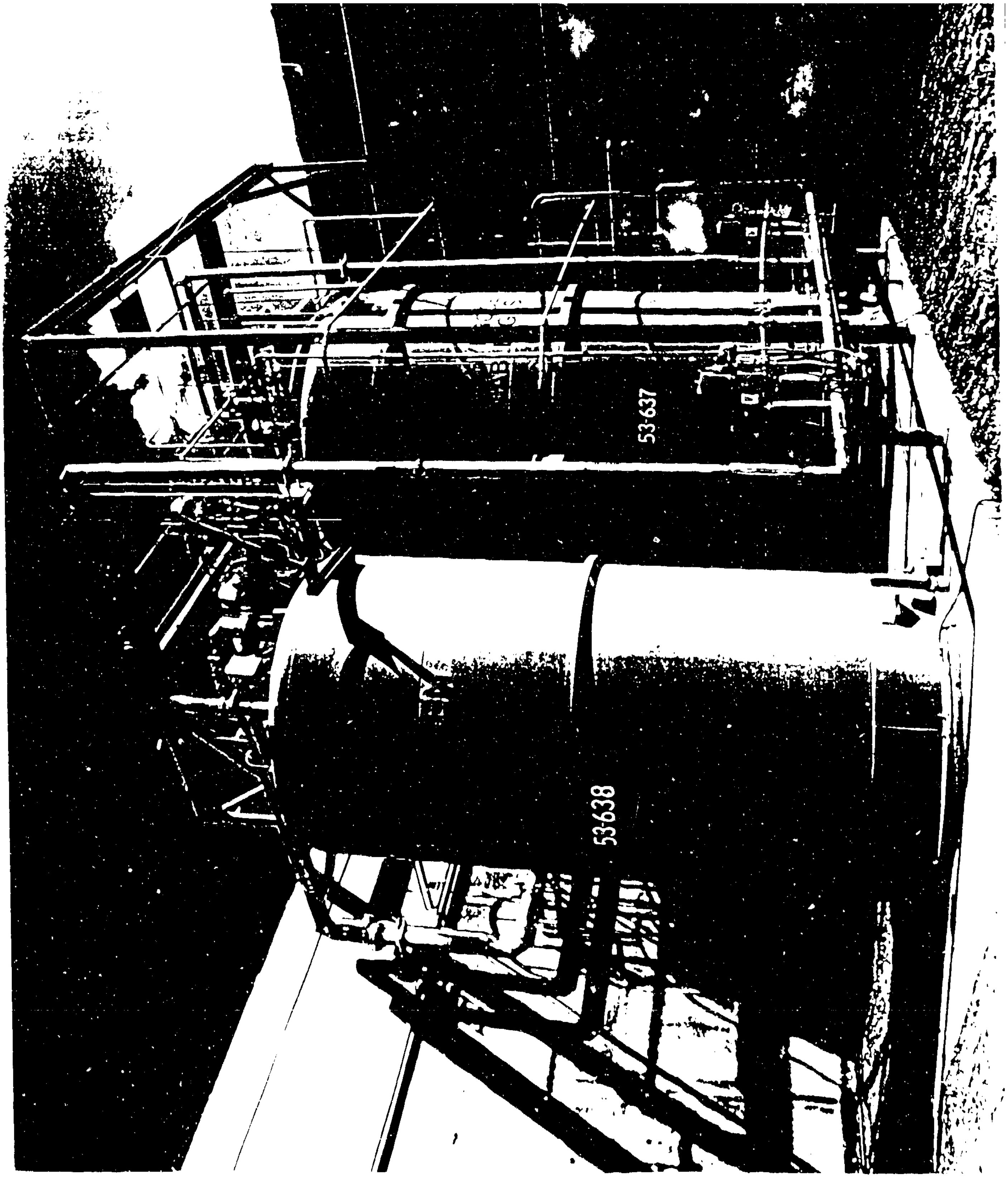


Fig. 4 The liquid nitrogen and liquid hydrogen Run Dewars

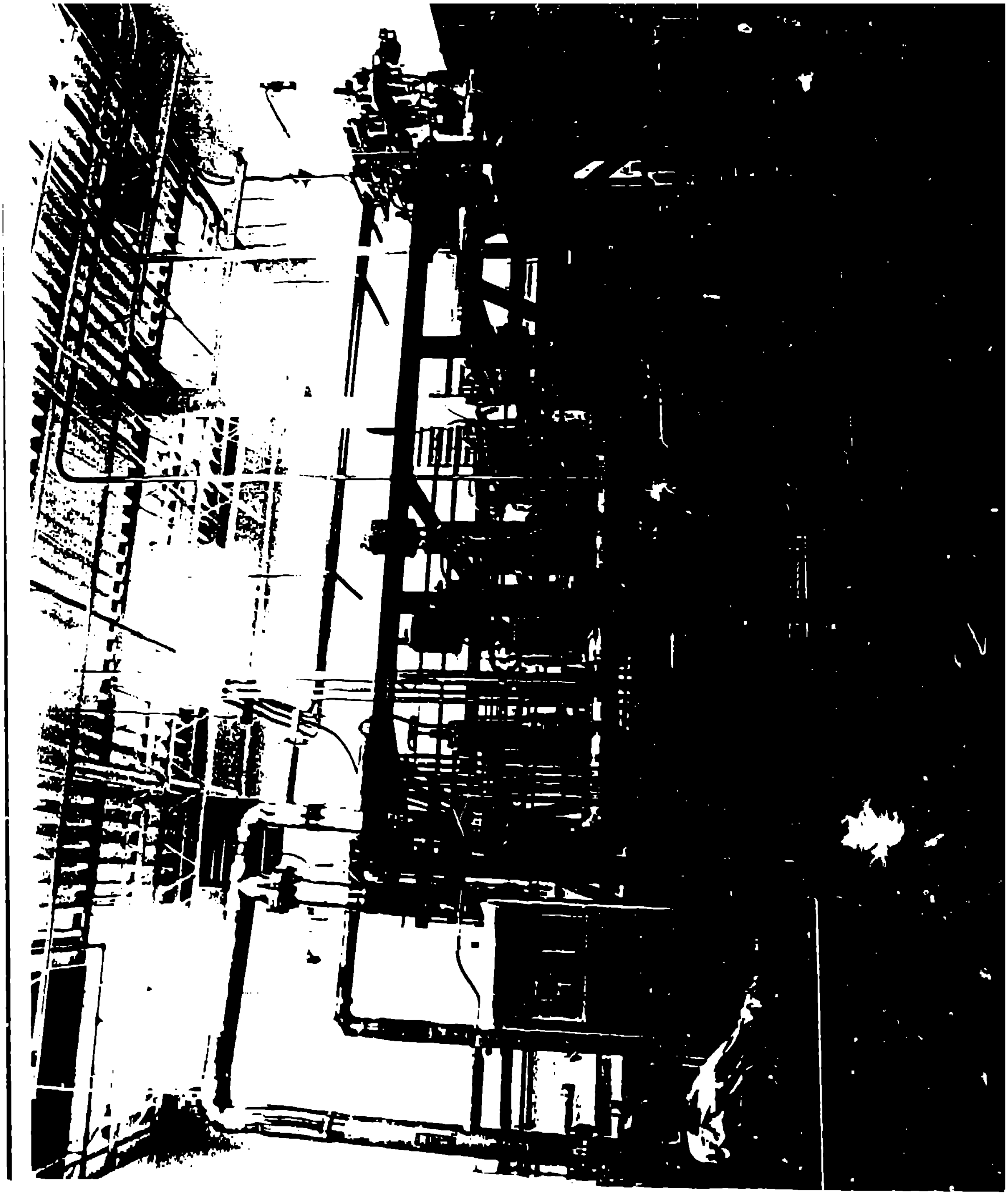


Fig. 5 The GTA equipment room containing the He circulation compressors, the purification system, heaters, bypass piping and valving, and local instrumentation.

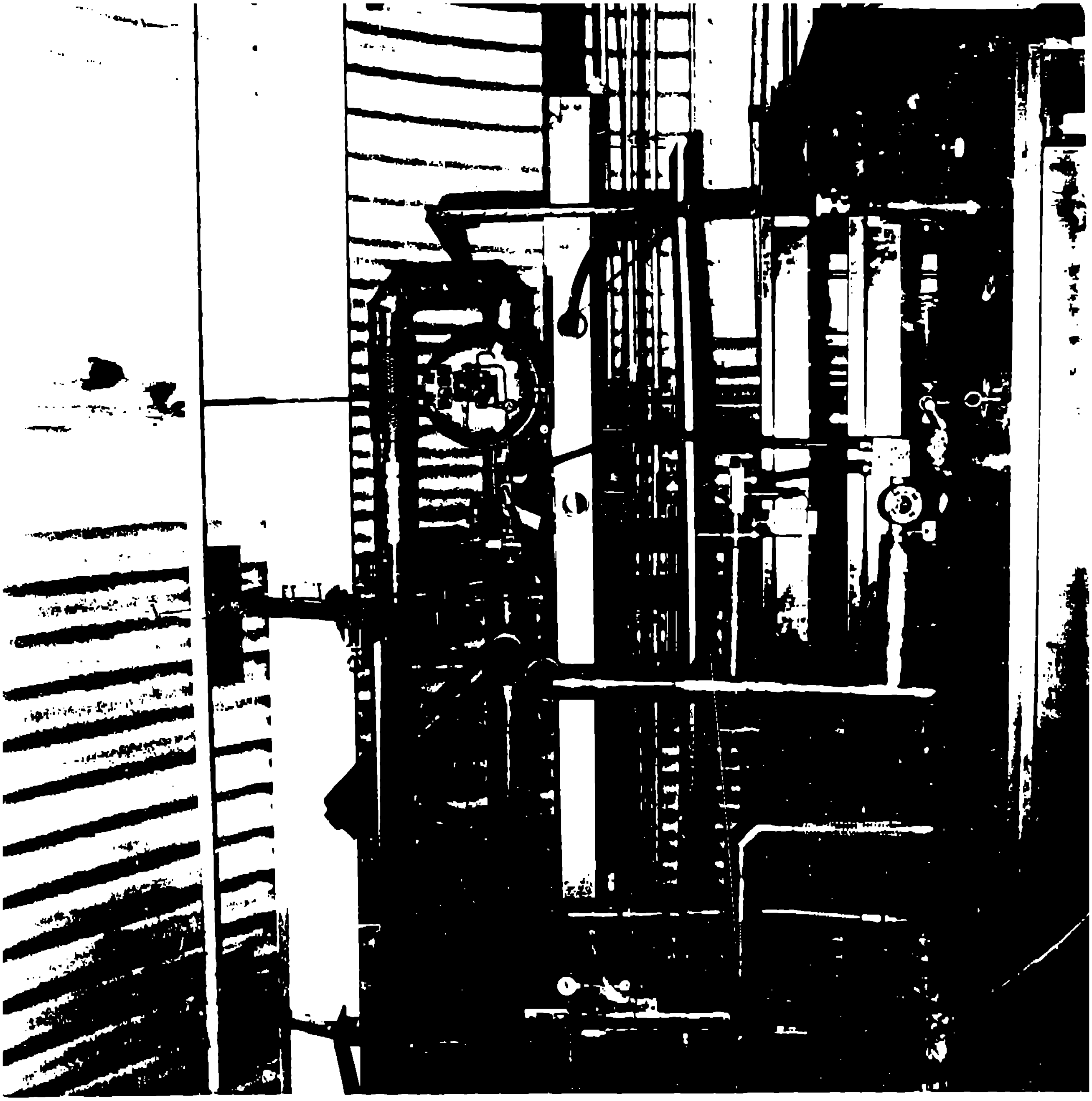


Fig. 6 GTA tunnel with the bypass valves CV 151 of the crycgenic cooling system.

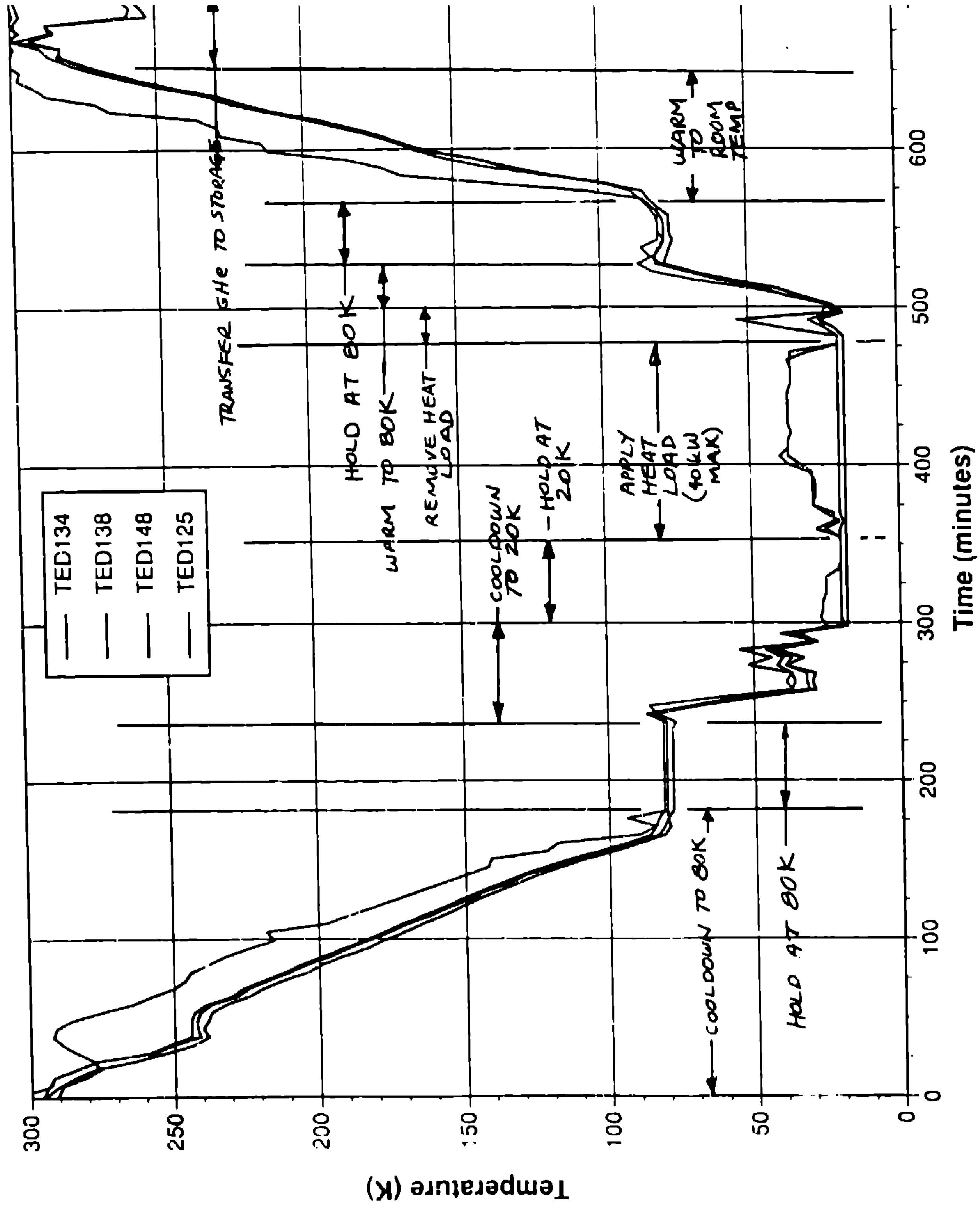


Fig. 7. Temperature history of the cryogenic cooling system checkout run.

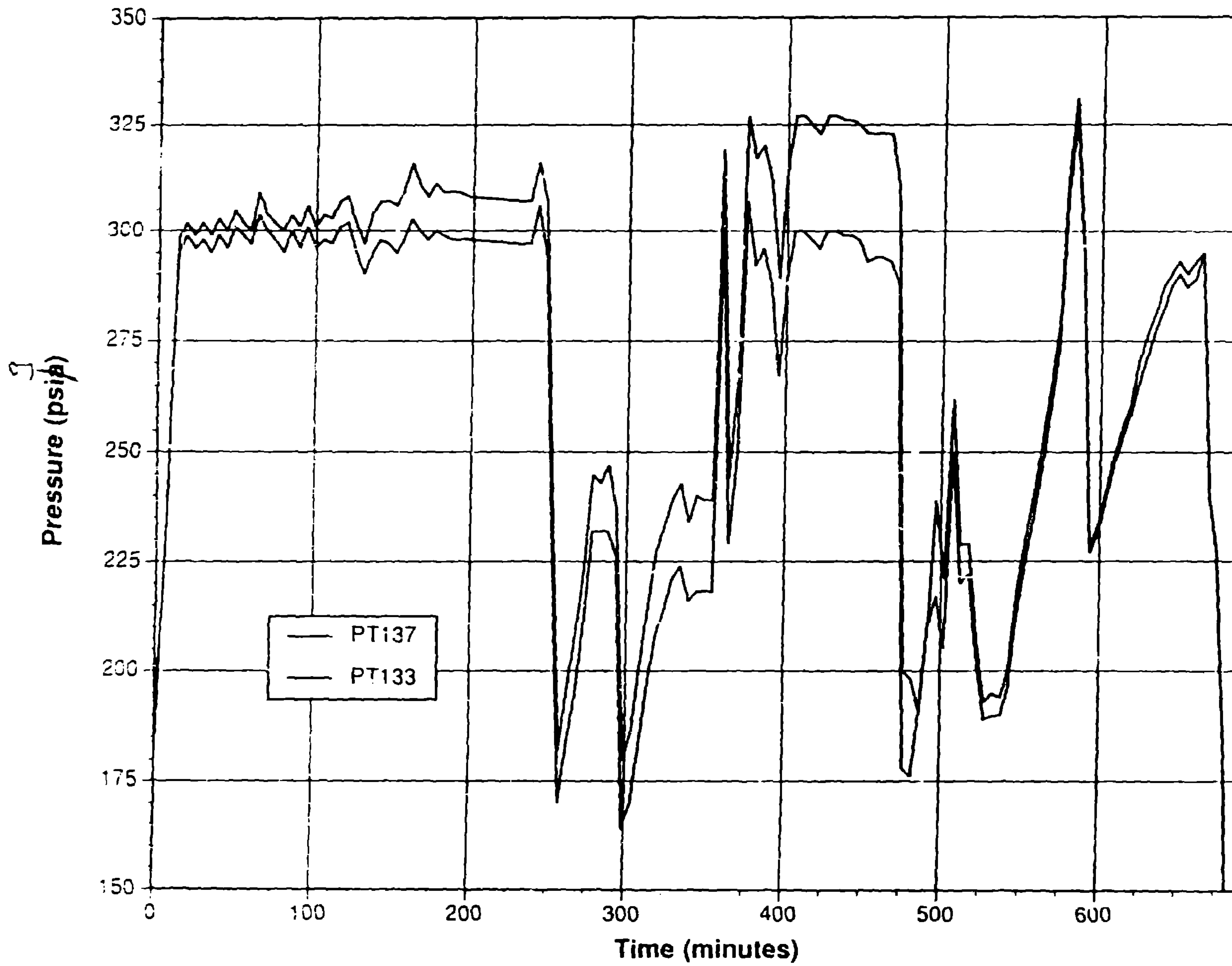


Fig. 8 Pressure history of the cryogenic cooling system checkout run.